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# The Role of Science in the Delta Visioning Process:

A report of the Delta Science Panel of the CALFED Science Program

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## I. Introduction

This report has been commissioned by the CALFED Science Program. Its objective is to provide a science-based platform for Delta visioning efforts that are expected to begin in the very near future. Accordingly, the panel's tenure and depth of work have been limited to part-time engagement over a 3-month period. The panel was charged to address key scientific understandings that should inform the vision-building process, to consider areas of uncertainty, and to suggest ways to bring science to bear as the vision process unfolds.

This report briefly describes the need for a new vision, and the likely role of science in the visioning process. It then describes key forces of change which plans and visions must accommodate. First-order drivers (such as subsidence, sea-level rise) are described in terms of issues and impacts, taking note of critical certainties and uncertainties that will bound the decision space. The report then poses likely criteria for gauging viability of visions and plans. Recommendations are offered to help guide the injection of science into the visioning exercise

## II. Background

In describing the need for a Delta Vision Process, the Administration's discussion draft comments:

> " *… a number of planning efforts and legislation*[1] *have reaffirmed and underscored prior findings that the current uses, resources, and ecosystem of the Sacramento-San Joaquin Delta are unsustainable over the next 100 years or more. These planning efforts have documented how changing environmental, hydrologic, climatic, and land use conditions can jeopardize the Delta's natural and human infrastructure under current regulatory requirements and management practices. There is also growing recognition that prior Delta strategic planning efforts have been too narrowly focused given the Delta's many uses and resources."* [Delta Vision Process Overview Draft, February 14, 2006)]

The decision to begin a new Delta Vision Process indicates a growing recognition of the Delta as a dynamic landscape and ecosystem, and an appreciation of the need to take fuller account of both historic changes and the driving forces that will shape the Delta of the future.

There is also a clear need to be more alert to the <u>pace</u> of change in the Delta, including changes currently underway that are vitiating options for rational management. New estimates of climate change and sea-level rise give cause for immediate action to avoid serious errors in land use and investment, and to prepare for the future. Urbanization of the Delta periphery and the parts of the central Delta exempt from Delta Protection Commission review are proceeding at a rapid rate, and thus far have not been considered in a comprehensive way.

In its report: Still Imperiled, Still Important, California's Little Hoover Commission noted:

> *The Sacramento-San Joaquin River Delta is a treasured and imperiled resource. …. It is not too late for the Delta … But restoring the estuary and managing the resource in a sustainable manner will require continuous political support, expert leadership, and smart management.*

Science can play an important role in providing the credibility necessary for political support, in guiding expert leadership, and in supporting the smart management that the Little Hoover Commission found to be needed.

## III. Science and The Vision Process

Several visioning processes that seek to project a desired future for the Delta are currently underway or in various stages of development. The draft Delta Vision Proposal (March 14, 2006) defines the most significant of these efforts, but much of the content and structure of the work remains to be developed. All efforts are likely to have two common features. First, although not explicitly stated as such, all will be based on evaluation of a range of scenarios. These scenarios involve projecting desired or anticipated future states of the Delta and are useful in evaluating the political, economic, and environmental efficacy of various outcomes. The second common feature will be the need for scientific information and criteria that constrain the range of scenarios developed. There is no standardized method for approaching this in a system as complex as the Delta. The range of services provided by the Delta is broad and the endogenous and exogenous forces acting on the Delta are complex and rapidly changing. Recognizing this complexity, we provide here a simplified approach to developing and evaluating scenarios for the Delta visioning process.

We focus here on the need to channel information simply and efficiently and suggest links to science-based advice that the visioning processes may need in the near future. The state of CALFED-related science falls into three categories: 1) High consensus understandings ready for immediate application, 2) knowledge where science is in flux, but where tools could be brought to bear quickly to provide inconclusive but useful advice, and 3) topics that are known to require inventory, monitoring, and research, and which irrespective of their importance, will simply not be ready for upcoming visioning efforts. Our principal focus here is on the science ready for immediate application. However, we recognize that on-going efforts to address current issues of concern, such as the Interagency Ecological Program Pelagic Organism Decline (POD) study, will help inform the visioning process as new information and understanding emerge.

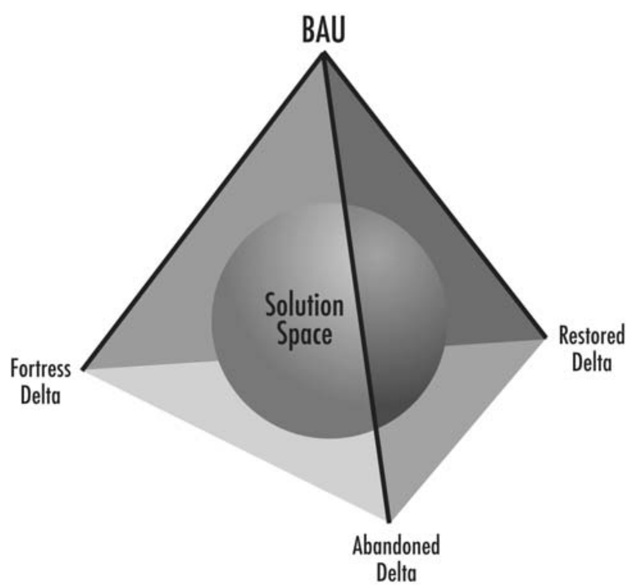
Finally, for the Delta visioning process to be effective, it must be acknowledged that a win-win option may not be ultimately achievable. The 2000 CALFED ROD attempts to seek solutions that will meet the needs of all Delta services and stakeholders through good coordination, management and intensive investment. As noted below, six first-order drivers of change in the Delta may limit a fundamental historical tenet of CALFED that "we will all get better together." We believe that the visioning process will need to make hard choices as to the degree to which all Delta services can be maintained. These tradeoffs fall within the realm of policy, not science. However, our report contemplates the likely form of the process needed to inform the discussion of such tradeoffs.

## IV. Scenario-based Visioning

The development of a vision for the future of the Delta inherently involves forecasting the future. Stakeholder input will generate needs, goals, and strategies for goal achievement that must be merged into an envisioned future state of the Delta. We do not expect specific actions and projects to be proposed. But scenarios need to be sufficiently concrete as to technology, time and location to be analyzed in terms of approximate cost and feasibility, and for possible conflict with other scenarios. Scenarios will be especially important if the visioning processes go beyond established positions and create new solutions to the Delta's long-standing problems. They may represent created visions, or they may represent what is likely to happen if no action is taken to respond to natural or societal changes

Given the wide range of services, the complexity of Delta issues, and the uncertainties about future Delta conditions, it is expected there will be numerous variations and permutations of scenarios. To simplify this process and to bracket the range of possible solutions, we developed a conceptual model for Delta futures defined by four end-member conditions (Figure 1). We postulate that these four end-members encompass and address all Delta issues and uncertainties that the scientific community will be asked to address. These end-members are not likely to be the ones that will be developed by the DVP, but they may form useful options to initiate discussion and as points of comparison or general classification for various scenarios. We believe that inevitably the Delta visioning process will arrive at an array of choices that lie within the solution space defined by these end-members, thereby incorporating elements of each.

**Figure 1.** End-point tetrahedron: bounding vision's solution space.



***Business as Usual***. As used here, the term "business as usual" is not meant to slight the considerable efforts underway as exemplified by the CALFED ROD. This end-member simply represents the continued attempt to perpetuate the existing landscape pattern through incremental resource management and levee upgrades. It would seek to maintain all key Delta features and infrastructure: agriculture, water management facilities and capabilities, highways, legacy towns, aqueducts, pipelines, transmission lines, towers, railroads, and disbursed recreation access as currently configured. This end-member includes current programs and proposals such as the Delta Improvements Package, the Ecosystem Restoration Program, and other CALFED, and constituent agency programs.

***Fortress Delta***. This end-member is similar to the first, but would go beyond incremental upgrades with massive investment to ensure that the current pattern or a planned alternative would survive forces of change. Full reconstruction might be proposed to protect water conveyance by upgrading the entire levee system, or by armoring a 30-mile through-Delta reach. A Fortress Delta concept might also be proposed to support extensive urbanization and related infrastructure. The urban version might look to the Netherlands for sound engineering standards and methods, not only in terms of the levels of investment, but in the requirements for continued attention to maintenance, monitoring, and advanced technology. Costs will be very high; so it will be important to compute the full costs and benefits of Fortress Delta, and not fall inadvertently into commitments that may have to be paid for later.

***Restored Delta.*** By this we do not imply restoration to historic conditions (as noted below, this is not possible due to the forces of change), but rather to give primacy to the Delta as a managed ecosystem with a suite of desirable ecosystem services. This approach would mimic or work in concert with natural forces, reduce exotics, and favor native species. Land uses in Delta polders could withstand temporary flooding under managed or unforeseen conditions. This scenario would permit some pelagic open waters to have saltwater / freshwater flux, and might provide for managed, periodic, temporary saline intrusions deep into the Delta. It would attempt to keep water temperatures low, and would provide for increased amounts of brackish and freshwater tidal marsh.

***Abandoned Delta***. While it is unlikely that abandonment would be come about as a matter of deliberate policy, it is nonetheless a plausible outcome from failure to act swiftly or forcefully enough to overcome the driving forces of change. In this scenario, the first-order drivers of change outlined below will dictate the eventual future condition of the Delta. Given the high costs in investments and changes in economic and environmental services associated with the three scenarios above, it is essential that the costs of inaction are also included in the evaluation.

Once developed, scenarios that lie within the solution space defined by the four end-members will need a process of evaluation and testing in order to narrow and refine scenarios. We propose that a two-step process be established that systematically evaluates all scenarios through a structured "filtering" program. The first filter involves identifying and evaluating the consequences of physical, biological and cultural change that is currently acting on the Delta. Assessment of these *First-order Drivers of Change* will lead to modification if not rejection of many scenarios, and perhaps lead to more viable alternatives. Once tested against the drivers of change, scenarios should then be evaluated for their ability to meet specified *Viability Criteria*.

## V. Guiding Delta Visions: First-order Drivers of Change

Traditionally, CALFED member agencies have approached Delta management based on a desire to maintain current conditions or to restore historic attributes. Until recently, consideration of future conditions has rarely appeared within agency planning documents in CALFED beyond acknowledgement of changes in water use demand. Yet, the scope and pace of landscape and ecosystem change in the Delta are likely to dictate the success and sustainability of all future management options.

The dynamic nature of the Delta forms an important constraint on the visioning exercise. Scenarios that are dependent on maintaining existing or historic conditions are less likely to be viable than those that anticipate or are adaptable to current trajectories of change. Based principally on CALFED science's current understanding of the nature of change in the Delta, we identify here six first-order drivers of change in the Delta. These drivers are likely to significantly alter the Delta over the near- and long-term and are independent of or unaffected by day-to-day management activities. These drivers include: subsidence, sea level rise, regional climate change, seismicity, exotic species and population growth/urbanization. Each of these drivers will have, or has had, a significant impact on the Delta at variable length and time scales. All will require some form of management response, regardless of which vision is eventually adopted for the Delta. All are a product of anthropogenic activities that have altered, and will continue to alter, landforms, hydrologic conditions, and the environmental services of the Delta.

We have six primary drivers of change, but compelling arguments can be made that others should be included, and that they may even prevail in terms of impacts on particular programs or scenarios. These would include such important problems as: mercury, organic carbon, food supply/food web conditions, and vectors. We have not commented on these because while they present significant issues, they are either derivatives of first-orders of change or can be directly managed.

For each of these drivers we identify the issue, and then describe the potential impacts on the Delta that should be considered in the visioning process. These are broken up into *Critical Certainties*—those impacts which, based on available scientific information are highly likely to happen—and *Critical Uncertainties*—those needing further research and understanding before being incorporated into the visioning process.

### Subsidence

*The Issue*: The hydrologic, ecologic and economic conditions of the Delta are principally a product of its reclamation history. The 1100 miles of levees used to drain the roughly 700,000 acres of tidal freshwater marsh forms the channel network that, in conjunction with tidal action and freshwater inflows, controls Delta hydrodynamics and supports all land use activities. Exceptions to this are the modifications in the channel network associated with shipping and flood control. Farming activity over the past century inside of the levees has led to the most significant landscape change recorded anywhere within the Delta region. As discussed in numerous reports, subsidence has created a profound state of disequilibrium in the Delta and an inherently unstable landscape condition.

Subsidence has been and will continue to be an important first-order driver of change in the Delta. The recent report by Mount and Twiss (2005; and reports cited therein) demonstrated that historic subsidence of the Delta has led to multiple islands with average elevations of greater than 15 ft. below mean sea level, and several islands with local elevations as great as 30' below sea level. Based on the distribution of peat soils, subsidence will continue into the near future as long as farming is maintained as the principal land use activity of the Delta. The most concentrated historic and future subsidence has occurred and will continue to occur in the central and western Delta, with reduced amounts anticipated in the periphery of the Delta.

*Impacts*: Subsidence influences all aspects of Delta management activity. These stem from four critical certainties:

> *Critical Certainty 1*. Over the course of the last 100 years, subsidence has driven the evolution of levee construction in the Delta. The dramatic subsidence of land and the increased differential between water surface elevations in the channel and the interior depths of islands has increased levee instability. This has increased demand for taller and wider levees, along with increasing demands for engineering. Continued subsidence will increase levee instability and increase demands for levee improvements. *Critical Uncertainties*: geotechnical conditions of levees and their foundation materials, and necessary modifications to support continued stability.
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> *Critical Certainty 2.* The potential consequence of catastrophic island filling events has major implications for management of the Delta. Rapid filling of the islands during low-flow periods leads to intrusion of brackish water into the Delta (CALFED, 2005) with broad-ranging impacts on water quality and aquatic habitats. In addition, island failures create increased pressure on adjacent levees due to enhanced underseepage and potential wave erosion. All current trends (see additional first-order drivers) point to an increased likelihood of Delta island failures in the future. *Critical Uncertainties*: hydrodynamic conditions and water quality conditions associated with single or multiple-island failures.
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> *Critical Certainty 3.* Filled subsided islands, such as Franks Tract, impact the volume of the tidal prism and alter local hydrodynamics, with resulting changes in water quality and habitat. The configuration of levee breaches and their interaction with surrounding tidal channels, coupled with the size and depth of the island dictates the magnitude of interaction and its water quality consequences. Current trends indicate the high likelihood of multiple flooded islands, particularly within the western and central Delta, with potentially significant increases in salinity. *Critical Uncertainties*: impacts depend upon which islands flood and the configuration of breaches.
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> *Critical Certainty 4.* Landscape-scale restoration efforts that seek to re-establish tidal freshwater marsh habitat are directly affected by historic and future subsidence. The magnitude of subsidence, particularly within the central and western Delta, severely limits the feasibility of developing large tracts of marsh habitat necessary to sustain functioning tidal ecosystems. In addition, some passive restoration approaches, involving levee breaching and island flooding, will lead to the development of low value open water habitat with little prospect of recovery through natural accretion. *Critical Uncertainties*: ecological response of plant and animal communities to widespread island flooding.

*Management Responses*: Currently, there is no indication that subsidence in the Delta can be effectively reversed on a regional basis within the period of time currently being considered by the visioning process. Unlike other land use practices (for example, logging, grazing, fishing, etc), there is no prospect that the lands of the Delta will “restore” themselves if farming is abandoned and the lands are allowed to naturalize. Thus, in the absence of information to suggest otherwise, regional reversal of the effect of subsidence should not be considered a viable option in the Delta. Scenario development must confront this issue without resorting to hoped-for advances in technology. However, localized subsidence reversal efforts may be effective in selected locations in the Delta with considerable levee stability, habitat and water quality benefits.

**Sea Level Rise**

*The Issue*: Although not often acknowledged in CALFED planning documents, the physical and biological character of the Delta is inextricably linked to sea level. Sea level controls the volume of the tidal prism and channel hydrodynamics in the Delta during most of the year when tributary inflows are moderate or low. As recent CALFED science efforts have shown, the hydrodynamics of the Delta and associated water quality are influenced principally by tidal processes. This is particularly pronounced in portions of the western, central and southern Delta where tributary inflow effects are greatly reduced. Changes in sea level will translate into changes in patterns of circulation, residence time, water quality and water surface elevations.

Sea level changes at the global scale are driven by two processes: changes in mass associated contraction or expansion of glaciers, and changes in volume associated with thermal expansion (summary in Mount and Twiss, 2005). In the Bay-Delta, sea level has been rising for the past 100 years due to both factors, with an approximate average rate of .08 in/yr (Ryan et al., 1999). This rate is similar to that recorded globally. Estimates of the range of sea level rise over the course of the next 100 years vary depending upon model assumptions about greenhouse gas emissions and differences between circulation models, but current estimates range from a total rise of between roughly 1 and 3 ft (Church and Gregory, 2001).

*Impacts*: During the next century, it is a Critical Certainty that sea level rise will impact the Delta. In natural estuaries, the physical characteristics—including the distribution of subtidal and intertidal habitats-- reflect the interaction between the inflow of freshwater and sediment, the *in situ* generation or organic sediment, and the tide and wave energy of the estuary. Changes in sea level alter estuarine dynamics, usually resulting in lateral shifts in sedimentation patterns and associated habitat conditions. Unlike natural estuaries, the Delta is no longer capable of accommodating changes in inflows, tides and wave energy. The 1100 miles of levee construction has "frozen" the Delta channel network in place and excluded hydrologic connection to historic marsh habitats (the most notable exception to this may be in the North Delta within the lower Yolo Bypass). As noted below, urban encroachment and levee improvement along the southern and eastern margins of the Delta also preclude future adjustments to changing conditions. The Delta's inability to self-adjust to sea level rise and associated changes in tide and wave energy virtually insures future impacts, both predictable and unpredictable.

To date, there has been relatively little scientific assessment of the regional impact of sea level rise on the Delta. The CASCaDE program will provide key information for the Delta visioning process, but this information is not currently available. Based on reviews of literature from outside of the Delta and summaries by Orr et al. (2003), we identify the following Critical Certainties that should be incorporated within and tested against any scenario development:

> *Critical Certainty 1.* The levee network of the Delta is tied, in part, to sea level and tidal range. State Hazard Mitigation Plan and Federal Pl 84-99 standards for the Delta link levee crown heights and associated freeboard with the water surface elevations based on the 100-year flood. These standards were last set based on 1986 hydrologic conditions and are out of date. Rising sea levels will require regular revision of standards for levee crown heights and associated levee widths, with significant increases in both. The impacts of sea level rise on levee heights will vary, depending upon location and tidal range. Impacts will be greatest in the central and western Delta where tidal range is largest. Impacts will be of less magnitude along the periphery of the Delta; but the extent of tidal influence to the east and south may well be significant. *Critical Uncertainties*: the magnitude of increase in sea level and resulting changes in water surface elevations in each part of the Delta.

*Critical Certainty 2.* Rises in sea level will increase the potential effects of subsidence in the Delta. The magnitude of the impact of flooding of any specific Delta island is a function of its location and the volume that lies below sea level. Increases in sea level directly increase this volume, regardless of whether or not subsidence is continuing. *Critical Uncertainties*: as above.

*Critical Certainty 3.* Increases in sea level will translate to changes in the tidal prism and channel hydrodynamics in the Delta, with the greatest impacts on the western Delta. These increases will alter tidal circulation patterns in the Delta, presumably leading to increased potential for higher salinities during periods of low freshwater inflow. *Critical Uncertainties:* the specific response of the Delta to increases in the tidal prism is currently unknown. Tidal circulation patterns and water quality changes will show considerable local variation depending upon local conditions, particularly island flooding and the configuration of levee breaches.

*Management Responses*: The impacts of sea level rise are likely to be broad, but subtle due to the slow pace of change. This is analogous to the impacts of subsidence in the Delta; the effects were not appreciated on a year-to-year basis due to slow rates, but became significant when measured over a multi-decadal timeframe. Given the lack of visible change associated with sea level rise, institutional responses are likely to be delayed until the issue manifests itself as a regional problem with a limited range of expensive or politically unpalatable management options. For this reason, we see great value in CALFED Science factoring sea level rise into the visioning process as a first-order filter. The CASCaDE program, initiated by the USGS (http://sfbay.wr.usgs.gov/cascade/) with funding from CALFED and USGS, will provide a model-based analysis of the potential effects of sea level rise on Delta hydrodynamics and habitat conditions.

**Regional Climate Change**

*The Issue*: Along with sea level elevation, the physical and biological character of the Delta is a product of the inflows received from the Sacramento and San Joaquin watersheds. On-going and future climate change in California will have impacts on Delta ecosystems and ecosystem services (Knowles and Cayan, 2004). Data and modeling results indicate that California has been warming and will continue to warm over the next century, with an increase in average annual temperatures of 2-5$^{o}$C (Hayhoe et al., 2004). Depending upon the General-circulation Model (GCM) used, there are variable predictions for precipitation change, with most models simulating a slight decrease in average precipitation (Dettinger, 2005). Despite model-based variations in projected precipitation and temperature, there appears to be relative consensus on two key issues: 1) climate change will manifest itself through shifts in the timing, magnitude and duration of inflows to the Delta and 2) change will lead to greater interannual variation.

The change in rain/snow mix, particularly in the northern Sierra Nevada, is projected to lead to a shift in the timing of peak runoff in the Central Valley toward the winter (Dettinger et al., 2004; Hayhoe et al., 2004). Downscaled modeling efforts indicate that the change in timing is likely to be accompanied by an increase in magnitude and frequency of winter extreme precipitation events as well (Kim, 2005). Modeling efforts also indicate that the shift in timing of runoff not only impacts winter runoff events, but also leads to declines in spring and summer inflows to the Delta.

Climatologists have documented changes in California's climate during the latter half of the 20$^{th}$ century (summaries in Jain et al., 2005; Stewart et al., 2005), with general trends toward increasing interannual variability. Downscaled GCM-based simulations for California's climate during the 21$^{st}$ century indicate a continuation of this trend (VanRheenen et al, 2004; Kim, 2005), with the potential for increases in both critically dry and wet years (Maurer et al., 2006).

The prospect of regional climate change is one of the more challenging problems to integrate into the Delta visioning process. This stems from two principal factors. First, although there have been major recent advancements in climate and hydrologic simulation technology and understanding, there is still uncertainty both within and between competing models (summary in Dettinger, 2005). This is especially pronounced when GCMs are downscaled and applied to California. And second, the impact of California's changes in climate on the Delta will be modulated by adjustments in water resource system operations (Jenkins et al, 2004; VanRheenan et al., 2004). The magnitude of climate change coupled with operational flexibility will ultimately dictate the nature of shifts in inflows (Brekke, et al., 2004). However, despite these uncertainties, the broad consistency observed in modeling results suggests that Delta visioning efforts should be constrained by a regional climate change filter that acknowledges: 1) shifts in runoff timing from spring to winter, with lower average inflows during the late spring and summer; 2) increased frequency and magnitude of extreme winter inflow events; and 3) increased interannual variability and associated reductions in water supply reliability.

*Impacts*: The array of possible impacts of regional climate change on the Delta is too large to review here. Every environmental service currently supplied by the Delta will be altered by regional change. In order to simplify this issue to aid the Delta visioning process, we include here two Critical Certainties that are likely to require significant management responses over the course of the 21$^{st}$ century and will constrain some scenarios.

> *Critical Certainty 1.* Projected changes in frequency and intensity of extreme winter runoff events will increase pressure on Delta levees. Given the current condition of the levee network and its links to outdated 1986 standards, increases in flood stages will result in increased frequency of island flooding. Sea level rise and subsidence, discussed above, enhance both the potential for, and consequences of higher flood stages in the Delta (Mount and Twiss, 2005). The impacts of increased frequency of island flooding is discussed above and includes broad impacts to Delta infrastructure, ecosystems, water quality, and water supply reliability. In addition, changes in inflow hydrology will require regular, upward revision of levee standards in the Delta. *Critical Uncertainties*: magnitude of stage changes, susceptibility of levees to failure, specific impacts of levee failures.
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> *Critical Certainty 2.* Although water resource operations will mute interannual variability of inflows, Delta visioning must anticipate the potential for significant impacts associated with higher ambient air temperatures and extended periods or increased frequency of low inflows during spring and summer. This will have a significant impact on water quality within the Delta in three ways. First, poor water quality inflows, particularly from the San Joaquin River, are commonly associated with dry and critically dry years when agricultural return flows and urban discharge dominate water quality conditions. Significant modifications in water operations are required during these periods to meet current water quality standards and flow conditions, particularly in the south Delta. Failure to meet these standards may increase under current climate change scenarios (VanRheenan et al., 2004). Second, low inflows amplify the influence of tides on Delta circulation patterns, leading to the potential for increases in salinity, most notably in the western Delta and Suisun Bay. The maintenance of current X2 salinity standards will likely become more difficult due to low inflows. Third, regional warming will not only change inflow patterns, but will lead to increases in temperature within the Delta. As recently discussed by Bennett (2005) and others, even modest increases in water temperatures of 2$^{o}$C have major impacts on spawning and recruitment success of native fishes, particularly Delta smelt. *Critical Uncertainties*: magnitude of water quality changes in the Delta in response to declines in spring and summer inflows.

*Management Response*: As noted above, changes in runoff conditions will be modulated, in part, by adjustments in water resource and flood control operations. However, there is no indication that current operational flexibility will accommodate the nature of change projected by current climate change models. Therefore, it is prudent to incorporate into scenario testing the assumption that regional climate change will lead to increased high winter flows, decreased spring and summer flows and increased variation in flows between years. Current modeling efforts under the CASCaDE program will provide key information for the Delta visioning process in this regard.

**Seismicity**

*The Issue*: In their original assessment of the dynamic nature of conditions in the Delta, Mount and Twiss (2005) argued that there are two types of landscape change that will impact the Delta in the future: gradual change, such as those described above, and punctuated change, involving dramatic, rapid reorganization of Delta channel networks over relatively short periods of time. A long-neglected, first-order driver of punctuated change in the Delta is seismicity. The Delta lies in close proximity to at least five major faults that are capable of generating modest ground accelerations, particularly in the western Delta. Multiple seismic risk assessments for the Bay Area indicate that these faults pose an increasing risk for severe shaking, with estimates that there is roughly a 2-in-3 probability that the Bay Area will experience a large magnitude quake in the next 30 years (http://quake.usgs.gov/research/seismology/wg02/). The precise response of Delta levees to seismic shaking cannot be predicted due to sparse geotechnical data on embankment and foundation conditions and the fact that no significant quakes have affected the Delta since the construction of high levees. However, multiple summaries, including a recent synthesis conducted for the CALFED Delta Levee Integrity Program (Torres, 2000) describe the risk of levee failure during earthquakes as medium to high for the entire western and central Delta. Even modest quakes with recurrence intervals of 100 years are capable of causing multiple levee failures and island flooding.

*Impacts*: The hydrologic, ecologic and economic consequence of rare, high-intensity seismic shaking events in the Delta has not been extensively studied. This is a focus of the current Delta Risk Management Study (DRMS) being led by DWR and CDFG, with results anticipated within the next two years. Preliminary results presented by CALFED (2005) for a large quake, indicate significant potential for widespread levee failures and island flooding, with the likelihood of multi-year disruptions in water supply and water quality and permanent flooding of multiple islands. For the purposes of guiding the Delta visioning process, and until the DRMS studies are available, scenarios must filter the following Critical Certainties:

> *Critical Certainty 1.* Rare, intense seismic events have the capacity to substantially alter all Delta management efforts, including water supply reliability, water quality, ecosystem restoration, transportation and recreation. All islands within Damage Potential Zones I and II identified within the Torres et al. (2000) report should be considered at risk of catastrophic flooding, with greatest risks in the western Delta in closest proximity to major faults. For large seismic events, it is highly likely that multiple islands will remain flooded due to the lack of current capacity for repairing numerous levee breaks. *Critical Uncertainties*: response of Delta levees to seismic shaking and future institutional capacity to repair breached levees.
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> *Critical Certainty 2.* Permanent, multi-island flooding is likely to occur within the western Delta during the next century. All preliminary modeling work indicates that this flooding will lead to salt water intrusion into the Delta during seasonal low inflows, principally through expansion of the tidal prism and alteration of tidal hydrodynamics. Along with abandonment of certain land use activities and infrastructure, and change in water supply reliability, multiple flooded islands and increased seasonal salinities will significantly alter the distribution, type and quality of

habitat. *Critical Uncertainties*: location of flooded islands and configuration of breaches will dictate magnitude of impact on Delta water quality.

*Management Response*: To date, there has been little response to the risk of levee failure due to seismicity on the part of CALFED or its member agencies. It is important to note that State Hazard Mitigation Plan standards and Federal Pl 84-99 standards for levees do not address the risks of levee failures during seismic events. Current proposals to repair and or upgrade levees to meet these standards will not address seismic risk. Because of the very high costs and complexity of upgrading Delta levees to withstand earthquakes, it is likely that any response, once chosen, will be multi-decadal in scope. The length of time involved and the potentially high costs of responding to seismic risk should be factored in to any proposed scenario.

**Exotic Species**

*The Issue*: The San Francisco Bay-Delta is one of the world's most invaded estuaries. During the past 150 years the estuary has become home to more than 250 exotic species of aquatic and terrestrial plants and animals (Cohen and Carlton, 1998), with roughly one third established in the freshwater Delta and the remainder in brackish or salt water habitats of the Bay. The successful introduction of numerous exotics into the Bay-Delta system stems from three factors: numerous transport vectors such as ships and aquariums, a depauperate native biota with low invasion resistance, and high disturbance associated with human changes in the system. Exotics now dominate most habitats within the estuary, accounting for 40-100% of the common species, and up to 97% of the total number of organisms and 99% of the total biomass in some habitats (Cohen and Carlton, 1998). The impact of exotics on Bay-Delta food webs has been profound, particularly where benthic clams like *Corbicula* and *Potamocorbula* alter chlorophyll production and trophic structure, and aquatic weeds like *Egeria* overwhelm subtidal habitats (Kimmerer, 2004). All aspects of the ecology of the Delta have been significantly and, in most cases, irrevocably altered by exotics. As has been pointed out by researchers working in the region, we are no longer managing the Bay-Delta to maintain or restore native biodiversity. All food webs, including those that support desired native and introduced species, are populated predominantly by exotics. Rather, we are seeking to manage native species within constantly changing ecosystems composed of a mix of native and exotic species.

*Impacts*: The scope and scale of the impact of exotic species on the future of the Delta is inherently difficult to incorporate into the visioning process. This stems from the complexity of species interactions, the myriad potential responses of disrupted ecosystems to changes in conditions, and uncertainty over which kind of exotic species will enter the Delta in the future. This complexity will make it tempting for the Delta visioning process to simply ignore exotic species and to presume that they will be managed adaptively. However, given their impacts on Delta environmental services, we believe it is important to test all Delta scenarios for potential effects on exotics. In order to simplify consideration, we identify two Critical Certainties about future invasions, based principally on the patterns and characteristics of historical invasions.

*Critical Certainty 1.* Delta ecosystems have been and will continue to be altered by exotics that enter and disrupt food webs. The impacts of these food web disrupters stems from changes in energy transfer to higher level consumers, particularly desirable fish species. Of these disrupters, two general groups have had, and will continue to have, the greatest impact. The first are zooplankton that have replaced native or naturalized zooplankton species. These replacements alter trophic structure, overall productivity and trophic efficiency. This impact has been severe in the mesozooplankton of the Delta, where a shift to small, exotic copepods has reduced the availability of a food source for larval and juvenile fish (Kimmerer, 2004). The second are the exotic grazers, particularly the bivalves. Depending on flow and water quality conditions, the grazers can cause dramatic local reductions in phytoplankton biomass in portions of the Delta (Jassby et al., 2002; Lopez et al., 2006). The grazers also reduce zooplankton abundance and species composition through predation or competition for food. Many exotic grazers appear to be favored in the Delta where water quality conditions remain relatively static. *Critical Uncertainties*: type, timing and impact of exotic food web disruptors and their response to changing inflow and habitat conditions.

*Critical Certainty 2.* The Delta is currently, and will continue to be, fundamentally altered by ecosystem engineers: organisms that change physical habitat conditions in ways that alter the availability of resources for other species (Jones and Lawton, 1994). This alteration involves changes in substrate, food and light availability, or water quality that modify or create habitat, often to the detriment of native species. In the Delta, aquatic weeds are prominent ecosystem engineers in subtidal, low velocity settings (Brown, 2003; Nobriga et al., 2005), with an aquarium plant, *Egeria densa* and the water hyacinth, *Eicchornia crassipes*, being the most notable examples. Like food web disrupters, ecosystem engineers appear to be favored in conditions that promote flow and water quality stability. *Critical Uncertainties*: type, timing and impact of exotic ecosystem engineers and their response to changing flow and water quality conditions.

*Management Response*: As Choi et al. (2005) point out, the number of exotics that enter the Delta in the future can be reduced through various management practices, such as changes in the exchange of ship ballast. However, even the best management practices will not eliminate introductions. Rather, the regional scope and pace of invasions in the Delta and the uncertain response of exotics to changes in physical conditions will undoubtedly require significant experimentation and adaptive management.

**Population Growth and Urbanization**

*The Issue.* Any visioning exercise must recognize the interactions between human-induced changes on the landscape, changing demand for Delta environmental services, and the feasibility of future management options. Population forecasts indicate that California's population may reach 90 million residents by 2100. As noted in the State Water Plan, this growth in population will change the nature and timing of demand for water resources, directly and indirectly impacting the future of the Delta. Along with increases in demand for reliable irrigation and drinking water supplies, one of the most important, and often ignored, influences that population growth has on the Delta is through urbanization. As with most regions of California, the periphery of the Delta is undergoing rapid urbanization. Present and future population growth increases the demand for land for development, particularly in areas in proximity to the Bay Area, Stockton and Sacramento, resulting in conversion of open space, primarily agricultural land, to residential and commercial use. Estimates prepared by staff for the California State Reclamation Board indicate that as many as 130,000 new homes are projected for construction within the legal Delta in the next decade.

We have chosen here to include urbanization, along with water demand as a first-order driver of change in the Delta. Under most circumstances, urbanization would be viewed as a second-order effect, reflecting land use choices that can be managed in a way that comports with regional and state-wide planning objectives for the Delta. However, the institutional setting in California regarding land use creates significant challenges for managing the impacts of urbanization on the Delta. Land use decisions are controlled by local and county governments, which seek significant potential economic benefits from increasing development in their communities. Outside of the Primary Zone of the Delta, there is no institutional mechanism in place to integrate local planning efforts into regional planning efforts. And the ability of the Delta Protection Commission to prevent future urbanization within the Primary Zone, under the 1992 Delta Protection Act, may be limited or subject to adjustment by future legislation and local governments.

*Impacts*: The potential impacts of population growth and urbanization have not been considered systematically as part of CALFED-sponsored science. We see three Critical Certainties that will need to be incorporated in the Delta visioning process:

> *Critical Certainty 1.* The Delta currently supplies a portion of the water supply to 23 million people in California. Although projections for future water demand vary, few are predicting a decline in the demand for drinking water and irrigation in the future. The 2005 California State Water Plan (Bulletin 160) recognizes that demand will continue at roughly current levels or higher until 2030 and beyond. Although this Critical Certainty is a statement of the obvious to most working in the Delta, scenarios that impact the timing, amount, and quality of water, both within and outside of the Delta, must identify alternatives to meet future demand or methods used to reduce demand. *Critical Uncertainties*: market forces, such as crop prices and the increasing use of water markets and banks, and advances in technology, such as water re-use and recycling, that will affect demand for Delta water (see reviews of issues in the State Water Plan and Lund et al., 2003).
>
> *Critical Certainty 2.* Unlike most land uses in the Delta, on-going and future urbanization is largely irreversible and self-accelerating. The construction of cities within or along the margins of the Delta is committing government to supporting urban land use into the indefinite future. This current trend will reduce or eliminate flexibility in management of the Delta, shifting the emphasis away from improving water supply, water quality and other ecosystem services (such as farming, habitat, recreation) to protecting urban centers and improving transportation corridors and other necessary infrastructure. In addition, as demonstrated repeatedly throughout the Central Valley, urbanization leads to increases in land values in adjacent farm areas, which, in turn, increases the demand for developable (agricultural) land even further from the point of current development, thus expanding the zone of urbanization. We see pressure for urbanization as a Critical Certainty for the Delta, particularly on the periphery of the Delta within the Secondary Zone, with broad and significant impacts on any Delta visioning process. *Critical Uncertainties*: local and state level legislative response to proposals to urbanize the Delta.

*Management Response*: Assessing and managing for future water supply demands within and external to the Delta have well defined federal, state and local agencies that are capable of addressing the future and generally working in concert. In contrast, no state or federal agency currently has the capacity to manage development of the periphery or the interior of the Delta. All state and federal agencies with jurisdiction merely respond to local initiatives, rather than develop and implement regional approaches. The CALFED visioning process will need to address the apparent disconnect between locally-driven and regional or statewide planning objectives.

There has been no comprehensive review of the impacts of the drivers of change in the Delta, making it difficult for stakeholders and agencies involved in the visioning process to systematically incorporate this information. The research and management communities of course have studies and expertise, but this will have to be marshaled and interpreted for vision participants. A body of CALFED-sponsored research efforts can form a partial foundation for scenario filtering. A partial list of applicable CALFED efforts is summarized in Appendix A.

## VI. Viability Criteria.

The first-order drivers of change will modify, eliminate or help create options for the Delta. A systemic approach is needed to assess the impacts of change on scenarios. A second filter should be synchronously applied that tests the viability Delta scenarios as each driver of change is assessed. Viability in this case refers to the social and economic sustainability of Delta scenarios in the face of change. We recognize that this process is policy-driven and much of it lies outside the direct involvement of CALFED science. However, science will be needed to provide independent, factual advice and information to aid in he policymaker's choices.

Based on our assessment of the range of future conditions for the Delta, as bracketed by the four end-member options and impacted by the six first-order drivers of change, we have identified five key viability criteria that should be addressed through the visioning process and will require scientific input. This is not a complete list and we can envision multiple additional criteria. However, the viability criteria listed here are those most likely to require substantial scientific input and involvement. These include:

***Robustness.*** All Delta scenarios will need to be assessed based on their robustness and resiliency. The driving forces acting on the Delta will stress any infrastructure constructed to manage or enhance Delta services. Robustness and resiliency in this case is the ability to resist to these changes. For example, are efforts like the South Delta Improvement Project, a critical component of the Business-As-Usual end-member, resilient enough to withstand changes in runoff and sea level, or will they be obsolete within a moderate period of time and require removal or modification? Science will directly inform this evaluation by identifying the impacts of change and the potential for failure points.

***Expediency.*** With the exception of Business-As-Usual, all future Delta options will require considerable time to complete, possibly involving phasing. Those scenarios which can be completed relatively quickly or have embedded adaptive management strategies that allow for changing direction are least likely to be overwhelmed by the drivers of change before they are completed. Since the drivers of change are probabilistic, science will play a key role in comparing the risks of various scenarios requiring long time periods to complete.

***Feasibility.*** The scope and scale of problems facing the Delta is large. The solutions to the Delta, as developed through the visioning process, are likely to be complex and expensive. Throughout the visioning process, science will be needed to provide independent assessment of the costs of managing landscapes for specific Delta services and the technological feasibility of those management efforts.

***Benefits/Costs/Equity.*** As noted earlier in this report, tradeoffs in the provision of Delta services are expected across alternative scenarios and management plans (win-win solutions are unlikely). Weighting of these tradeoffs falls within the political realm, but quantitative information on the benefits and costs of alternative futures helps inform the visioning process by identifying inefficient solutions. In addition, viability of scenarios and associated management options should be assessed in terms of their equity implications; i.e., information on how the benefits and costs are distributed across society and over time, insuring just outcomes.

***Reversibility/Adaptability.*** In considering the drivers of change and their impacts on Delta scenarios, it is important to recognize that although change is inevitable, the rate and magnitude are less precisely known. For this reason, all scenarios should be evaluated for their adaptability and reversibility. Plans that can be phased and tested before full-scale implementation will have a much greater chance of success. Hardening of the Delta's configuration, as in the Fortress Delta end-member, commits management to long-term investments that are not easily reversible.

The linkage of drivers of change with viability criteria can be assessed through construction of a matrix. Completion of this matrix, formally, or in concept, will lead to a systematic and internally consistent assessment of each scenario.

**Figure 2.** Vetting ideas and scenarios.

| | **Viability Criteria** | | | | |
|---|---|---|---|---|---|
| **Drivers of Change** | *Robustness* | *Expediency* | *Feasibility* | *Benefits/costs/equity* | *Reversibility* |
| *Subsidence* | | | | | |
| *Sea Level Rise* | | | | | |
| *Regional Climate Change* | | | | | |
| *Seismicity* | | | | | |
| *Exotic Species* | | | | | |
| *Population Growth/urbanization* | | | | | |

As an example of how this matrix might be used, review of a proposal for peripheral or through-delta water transfer would ask under *Expediency*: "Can this be accomplished before the path is further urbanized? Review of a plan for shallow-water habitat might ask under *Robustness*: "Will this become lower-value deep water in the long run?"

## VII. Design of the vision process.

The design of the vision process itself lies beyond the scope of this report. However, the science interface should be crafted to mesh with whatever process is developed. Careful attention should be given to the role of science, since too much information provided at the outset of the vision process can overwhelm participants or make solutions seem impossible. Analysis, without a commensurate amount of creative productivity, can lead to paralysis. And, if science is seen mainly in a review mode and left to the end of the process, it may only provide critical review of hard-won solutions. Therefore in Appendix B we pose three alternative architectures for such visioning efforts, and point out some ways in which science can best be injected into the deliberations.

## VIII. Summary and Recommendations

We expect that the visioning process will involve multiple steps and will evolve as various groups share ideas in search of common visions. Science will be critical in providing guidance to participants in selecting and refining feasible alternatives from among the suite of possible visions. There are numerous national experiments that can be evaluated for the methods used in incorporating scientific information (e.g., Northwest Forest Plan, Everglades, Chesapeake, etc.), but each is tailored to their own unique geographic, cultural and resource characteristics. The process proposed here is designed to quickly and efficiently address the unique conditions of the Delta, which is being impacted by rapid change, and identifies those areas where science can be best incorporated into the visioning process.

The array of potential scenarios for a future Delta will lie within a solution space bracketed by four end-members: Business-As-Usual, Fortress Delta, Restored Delta, and Abandoned Delta. In the initial stages of the visioning process, we envision direct interaction between CALFED agency scientists and consultants and those charged with developing scenarios. As the scenarios gain substance, we recommend that scenarios selected for serious consideration be systematically evaluated using two key filters: the first-order drivers of change, and the viability criteria. A matrix, similar to one shown in Figure 2, should be developed to explicitly evaluates the viability of any given scenario against the drivers of change. This process will, in relatively rapid fashion, highlight potential issues associated with scenarios as well as important gaps in understanding that will need to be addressed. We urge that the science community be involved in different ways in different phases of the vision effort. In the early stages, science and management can help set the framework. To the extent that supporting information can be shared among planners and scientists dialog will be enhanced. Some examples of helpful materials are given in Appendix C. In mid-stream, science can provide well-grounded advice, and help avoid paths that might encounter conflicts or dead ends. Toward the end, science may help provide credibility to the difficult choices that must be pursued.

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## Appendix A. CALFED funded research efforts directed at first-order drivers.

| | |
|---|---|
| **Subsidence** | |
| ERP-98-C01 | Demonstration of Techniques for Reversing the Effects of Subsidence in the Sacramento-San Joaquin Delta: Phase 1--Twitchell Island |
| SCI-05-C30 | Rates and Evolution of Peat Accretion (RE-PEAT) in the Sacramento-San Joaquin Delta, California |
| **Climate/Sea Level Change** | |
| SCI-05-G01-84 | CASCaDE: Computational Assessments of Scenarios of Change for the Delta Ecosystem |
| ERP-02-P38 | Effects of Climate Variability and Change on the Vegetation and Hydrology of the Bay-Delta Watershed |
| **Exotic Species** | |
| ERP-97-C07 | Preventing Exotic Introductions from Ballast Water. |
| ERP-99-N10 | Assessing ecological and economic impacts of the Chinese Mitten Crab |
| ERP-99-N09 | Effects of introduced species of Zooplankton and Clams on the Bay-Delta Food Web |
| ERP-00-F10 | Determining the Biological, Physical and Chemical Characteristics of Ballast Water Arriving in San Francisco Bay |
| ERP-02-P32 | Distribution and abundance of shrimp, plankton and benthos in Suisun Marsh: Tidal marsh as a refuge for native species. |
| ERP-02-P26 | Life History of Egeria densa in he Delta: Factors Controlling Production and Fragment Viability |
| **Urbanization** | |
| SCI-05-G01-84 | CASCaDE: Computational Assessments of Scenarios of Change for the Delta Ecosystem |

**APPENDIX B. Frameworks for a science-based visioning processes:** crafting support to fit the architecture of the visioning process

One role of science is to help make the visioning process more grounded and increase the likelihood that visions can be successfully implemented. Science can help reduce the level of uncertainty, or at least let policy makers know when they are "flying blind". We believe that Delta visioning will have several distinct characteristics. It will attempt to be bold, as continuation of current policies with marginal changes in management are likely to fail to control the forces acting on the Delta. Second, it will not start with a clean slate. The Delta's services and problems are well understood; the task is to forge a shared vision of how services can be continued as fully as possible, and to set the stage for the equitable allocation of scarce resources. Third, it will need to deal with a high level of uncertainty.

Decision-making behavior under uncertainty can be seen in terms of a continuum.

**paralyzed | overly-cautious | deliberate, rational | bold | cavalier | blind**

Scientists commonly lean toward the left side of this spectrum; and policy makers more to the right, which is to be expected given their differing roles. For today's visioning for the Delta, we hypothesize an impatience with CALFED's deliberate pace, and that visioning will target the bold side. To the extent that this turns out to be true, science support can be seen as less one of providing solid answers (as it might in the cautious or deliberate mode), and more one of illuminating uncertainties, helping to keep visioning from venturing into the realm of the cavalier.

Scientific and technical support for the Delta Vision Process will need to be tailored not only to the degree of caution, as above, but to the particular type of architecture that is employed. The tools, procedures and the organizational structure needed to pass information back and forth will vary depending upon the mode that is selected.

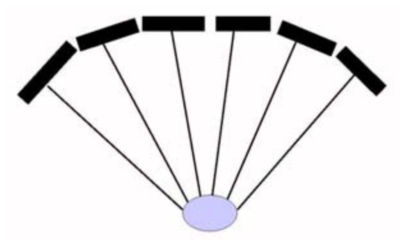
Here are just three examples of architectural structure, with some brief comments on each. For sake of clarity, these are caricatured as the "freight train", "parachute", and "wheel" approaches to planning and scenario building.

**Freight train**

In this architecture, tasks are set in sequence, the first informing the later ones so as to build toward a final product that has passed through all elements. This approach is common in engineering, where a single, highly developed design can be put through a linear process. Advantages of the freight train are that later elements benefit from earlier ones, and plans can build toward a well-supported final product. An important disadvantage is that when new ideas are created at later stages, there may not be time or funds to recycle new ideas back through the process.

Science support for this approach usually consists of short-term task-oriented panels assisting each element. Support is often organized along single disciplines (as opposed to multi-disciplinary teams).

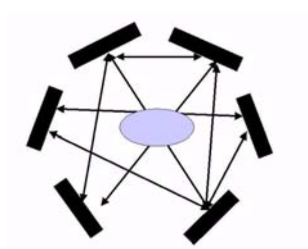
**Parachute**



In this model, the effort is parsed into groups that work in parallel to frame products that are then merged. The CALFED ROD can be seen as a variation on the parachute paradigm. For the vision process, this template might well be used with care. While stakeholder groups may successfully create their separate visions of what the region should become, each vision can become a political rallying point, incapable of being merged into a unified plan. In this structure, conflicts may not become evident until late in the game.

Science support for the parachute model consists mainly of pre-stating assumptions and models for the separate groups, and providing strong information support to each group throughout. On-call science support is needed for "if-then" testing of draft alternatives. This important part can be lost if insufficient time is available. Scientists are commonly organized into task-oriented multi-disciplinary panels to support each group; sometimes with a standing science board to provide continuity and oversight.

**Wheel**



**In this template, all elements start at the same time, with strong cross linkages.** Advantages of the wheel are that all elements are expected to collaborate from beginning to end. Participants are exposed to opposing and complimentary points of view early in the game and can revise their expectations accordingly. The range of possible outcomes can be self-narrowing, as problems with outlying ideas become clear. If planning support is prepared in advance, the participants may be able to move quickly into substantive debate and creative work.

One disadvantage of the wheel is that if participants expect that a win-win solution will be found, and if no such solution emerges quickly, the process can be so depressing as to fail. Transparent interaction across groups can illuminate harsh realities. This makes for good planning but tough politics. Another disadvantage is that high transaction costs and the difficulties of so much cross-element communication present a challenge. A high level of hands-on technical and scientific support is needed to move from positioning to creative collaboration. If the process takes on its own life and develops new ideas (a good thing), science and technical support may be unable to provide guidance quickly enough to keep up (not so good).

This kind of interaction requires a workshop approach (not a typical committee meeting or assignment of tasks to consultants). Sustained, intensive participation is required. New players or alternate stand-ins will disrupt progress.

Science support is quite different for this model. Science can help with setting ground rules and identifying context and conditions that would influence the work of the entire group. The more pre-statement of shared context the better. Rapid review, analysis, and advice must be provided as new ideas and compromise proposals emerge. A diverse standing science panel could be created to observe and assist as requested. Since conflicts come out in the open throughout the process, science input may need to be coupled with alternative dispute resolution tools (such as facilitated joint fact finding).

There are many other architectural caricatures. The point of this discussion has been to suggest that careful attention should be given to the format of visioning efforts, and to point out that science and technical support must be crafted to fit the needs of the structure.

**Appendix C. Examples of materials to support both science and policy in the visioning process.**

To the extent that planners, policy makers, scientists and resource managers can share and update working documents and maps, the process of collaboration and rapid review and comment would be facilitated. Information in the DWR Delta Atlas is appropriate, but should be updated with the most current information.

The following maps and digital files are all available (with differing dates and levels of detail), and serve as an example of what could be made available physically and on-line. These maps exist as digital GIS layers at DWR or CDFG. Additional layers of interest are of course available at other agencies and university archives.

The vision process will not delve deeply into detailed designs and plans, but some of the detail will dictate the viability of proposed general land uses. Since a long list of factors does not make for ease of use in higher-level planning, some effort at classification and mapping would be useful. A digital library of key documents, maps, and links to information resources would be invaluable. Given that many disciplines and stakeholders must collaborate in this effort, an on-line information source should be developed. Several agencies, especially CDFG, have templates that could be used.

**For each island:**

- Acreage
- Land use types
- Levee perimeter (and classification if available)
- Elevation
- Subsidence projections
- Seismic risk zone
- FEMA status
- Infrastructure: rail, roads, pipelines, aqueducts, gas fields, water operations facilities
- Failure history
- Evacuation routes
- Urban land uses
- Historic and cultural resources
- Population
- Recreation sites and facilities
- Formal plan designations
- Delta Protection Commission status
- Development changes underway. Pending, or planned
- Land ownership (public by type, private)
- National Wetland Inventory
- Island failure history
- Critical agriculture infrastructure facilities
- Agricultural intakes and returns
- Linkage to other islands (some islands depend upon access or resources on adjacent islands)

**Delta-wide:**

- Levees by type (and risk classification if available)
- General elevation, subsidence
- Subsidence forecasts

Organic soils, percent and depth
Seismic risk
City and County boundaries
LAFCO designations
General Plans
Williamson Act status
General land ownership
Delta Protection Commission boundaries
Regional Infrastructure
National Wetlands Inventory
Crop types
Land Use by category
Island failure history
Failure scenarios
Water operations facilities
Imagery, including GoogleEarth, & NASA WorldWind